Optically tunable metamaterials on lattice-matched InGaAs/InP

D.Seliuta[1,2], D. Zimkaitė[1], G. Šlekas[1], A. Urbanovič[1], J. Devenson[1], R. Adomavičius[1], and Ž. Kancleris[1]

[1]Center for Physical Sciences and Technology, LT-01108 Vilnius, Lithuania

[2]Vilnius Gediminas Technical University, LT-03227 Vilnius, Lithuania

***Abstract*—Optically controlled mode switching in the split-ring resonators deposited on the lattice-matched InGaAs/InP was demonstrated at excitation wavelengths 900-1200 nm. Using tunable excitation wavelength as well as split-ring resonators of different configurations attempts were made to optimize the mode switching conditions for application of tunable metamaterial for high-speed narrow-band THz modulation.**

I. INTRODUCTION

RECENTLY much attention has been payd to metamaterials trying to achieve efficient modulation at THz frequencies. The majority of the existing efforts on active devices are based on metamaterials incorporating semiconductors, which can change conducting properties by applying an external voltage or light. Particular advantage of the optical approach is the possibility of extremely fast switching with recovery times as short as tens of picoseconds [1].

Optical control of metamaterials can be realized by employing intrinsic semiconductor as a substrate under the resonators [1]. Insertion of semiconductor islands into specific parts of the resonators allows for the resonant frequency shift [2] or the resonant mode switching [3]. However, high femtosecond pulse energies are still required for the effective optical control. Besides, most of the work has been accomplished using silicon-on-sapphire substrates and short wavelength ~800 nm excitation. In this work, we demonstrate that effective optical control of planar metamaterials can be performed at longer wavelengths using lattice-matched epitaxial InGaAs layers on InP substrate. Our results could be a contribution towards development of terahertz communication systems using well developed fiber technology at telecom wavelengths.

II. RESULTS

For calculations we consider infinite planar periodic array of the split-ring resonators (SRRs) deposited on dielectric substrate using the unit cell approach. For calculation of electromagnetic field components in the unit cell finite–difference time–domain method was used. A differentiated Gaussian pulse was applied as the current source to excite wide band plane wave propagating from the excitation plane. The optical control was modeled by inclusion of semiconductor islands of variable conductivity which is related with the illumination intensity.

Metamaterial samples were prepared on lattice-matched epitaxial InGaAs 500 nm thick layers grown on InP substrates as planar periodic arrays (30x30) of single-split and double-split resonators (Fig. 1) by thermal deposition of titanium (10 nm) and gold (200 nm). The photoactive layers of InGaAs were processed: a) by wet etching of square mesas, b) by plasma etching with the photoresist patterns and SRRs as protective layers. Measurements were performed using standard THz time-domain spectrometer synchronized with the optical parametric oscillator allowing excitation of samples at wavelengths 750-1700 nm.

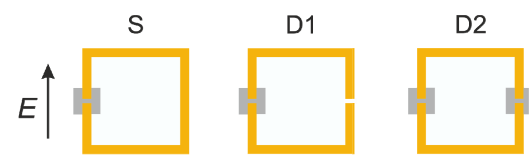

Fig. 1. Configuration of SRRs: outer dimensions of the resonators (yellow) 48 μm, width of the conductive stripes 4 μm, width of the split gaps 2 μm, periodicity of SRRs in both directions of a plane perpendicular to the incident beam 64 μm, InGaAs mesas (grey) 12 μm x 12 μm. *E* denotes polarization of THz beam

A few configurations of samples shown in Fig. 1 were designed to investigate the optically-induced resonant mode switching in SRRs. As follows from our calculations illumination of sample S results in quenching of the *LC* resonance at 340 GHz and the red shift of the dipole resonance. Red shift of the dipole resonance and appearance of the *LC* resonance was observed when illuminating sample D1. Illumination of sample D2 results in the red shift of the stop-band associated with the dipole resonance from 1300 GHz to 830 GHz. The optically controlled mode switching methods are analyzed as modulation schemes of a narrow-band THz radiation. Tunable excitation wavelength has been used to control the light penetration depth. The two device processing methods as well as the front-side and the back-side illumination experiments allowed for optimization of the excitation method. Experimental results are found in agreement with the model calculations. The largest resonant strength was observed at backside illumination of samples at wavelength ~1000 nm corresponding to the light absorption coefficient approximately equal to $1/d$ (d is the photoactive layer thickness).

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